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RESEARCH ARTICLE

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Evaluation of visual encounter surveys as a method for the rapid assessment of fish presence and relative density in high mountain lakes

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Abstract

1. Introduced fish are a widespread ecological threat in originally fishless high mountain lakes. However, basic distribution data are largely missing for most high mountain regions.
2. Using time-consuming standard methods (e.g. Nordic standard fishing nets) to assess fish distribution and relative densities at a relevant spatial scale can be impracticable, because of the large number of high mountain lakes. To overcome this problem, alternative rapid monitoring methods would be helpful.
3. Visual encounter survey (VES) is a candidate method that enables observing fish from the shoreline. It takes only minutes to implement and is already widely used for amphibian monitoring in high mountain lakes and ponds. VES was evaluated as a method for monitoring introduced salmonids and cyprinids (the most widespread fish families) in 52 high mountain lakes.
4. The probability of detecting both families by VES rapidly approaches 100% as the relative densities of fish increase, and false absences are restricted to populations living at low relative densities. VES also provides simple indications about fish relative densities, distinguishing between high-density and low-density populations.
5. As VES usually does not enable fish species identifications, we propose VES as a useful method to describe large fish distribution inventories, not needing high taxonomic detail, but necessary for planning large-scale conservation measures.

KEYWORDS

alien fish, conservation, detection method, fish stocking, monitoring, visual encounter survey

1 | INTRODUCTION

Introducing game fish (i.e. salmonids) for recreational angling in originally fishless mountain lakes is a widespread practice and a serious threat for native species and habitats (Ventura et al., 2017). Anglers also facilitate the spread of other non-game species used as live baits, such as minnows (*Phoxinus* sp.), which, once established, cause further ecological damage (Museth et al., 2007; Miró & Ventura, 2015; Miró, Sabás & Ventura, 2018). To address this conservation issue, it is a basic requirement to have reliable distribution data on introduced fish (Radomski & Goeman, 1996; Miró & Ventura, 2013). However, such data are usually scarce, lacking, not updated, and scattered in local archives and, therefore, inaccessible for many montane regions (Ventura et al., 2017; Tiberti & Splendiani, 2019). Given the situation, it would be beneficial for available data to be collated and published by fish management authorities and kept up to date. However, getting this basic information at relevant geographical scales remains a challenging issue, which involves from dozens to thousands of lakes, including many remote sites (Bahls, 1992; Miró & Ventura, 2013).

Assessing fish distribution over large mountain areas and keeping distribution data updated using standard methods (e.g. multi-mesh gill-netting; CEN, 2005) would require enormous monitoring efforts and is therefore unrealistic. To get around this difficult issue, alternative data sources can be used instead: data can be retrieved from previous studies/monitoring campaigns, fishery archives, interviews, or citizen science projects involving local people, anglers, park wardens, technicians, scientists, and so on. For example, Bahls (1992) and Miró & Ventura (2013, 2015) provided large fish distribution inventories based on fishery data and interviews. However, these sources of data can be absent for some regions or prone to errors (e.g. biased towards game fish distribution, or not updated) and their consultation can also be time-consuming. In general, the availability of first-hand field data would represent a great improvement.

Standard methods for fish surveys should represent the first choice whenever feasible, but extensive monitoring of high mountain lakes would greatly benefit from the availability of alternative, rapid methods for assessing fish presence and relative density at relevant geographical scales. A candidate method is visual encounter survey (VES), a rapid, non-manipulative method commonly used for amphibian monitoring along line transects (Crump & Scott, 1994). It has been widely used to assess the presence and abundance of amphibians along the shorelines of high mountain ponds and lakes (Knapp, 2005; Miró, Sabás & Ventura, 2018; Tiberti, Mangiacotti & Bennati, 2021). VES has already been used instead of standard methods to assess the presence or absence of fish in shallow mountain ponds, where the entire water body can be inspected from the shores (Knapp, 2005; Knapp et al., 2016). However, studies comparing the performance of VES and conventional methods (gill-netting and fyke-netting) for assessing fish presence and abundance in mountain ponds and lakes are absent so far.

In the present study, both VES and gill-netting/fyke-netting were used at the same sites to assess the presence and relative densities of salmonids and cyprinids in 52 mountain lakes in the western Italian Alps and Catalan and Aragonese Pyrenees. Field data were analysed to assess whether visual surveys can provide reliable and useful data on fish presence and/or relative abundance, and whether VES can be considered a reliable monitoring method not only in shallow lakes and ponds but also in larger and deeper mountain lakes. The reliability of data was assessed based on how VES results compared with gill- and fyke-netting results in both small and large lakes. To be considered reliable, VES results should provide (i) the same or similar detection probabilities as gill- and fyke-netting methods, not adversely influenced by lake size, and (ii) density indices significantly correlated with those achieved by gill- and fyke-netting methods.

2 | METHODS

2.1 | Study area and lakes

The study was conducted between 2006 and 2021 in 52 lakes with introduced fish fauna mostly from five protected areas in the Catalan and Aragonese Pyrenees and western Italian Alps: Aigüestortes i Estany de Sant Maurici National Park, Alt Pirineu Natural Park, Posets Maladeta Natural Park, Gran Paradiso National Park, and Mont Avic Natural Park (Figure 1). All study lakes are typical mountain lakes (Figure 2) with surface areas between 0.2 and 30.2 ha, cold and ice covered for 4–9 months per year, located close to or above the local treeline, with altitudes ranging between 1,618 and 2,747 m. Introduced fish include both Salmonidae (brown trout *Salmo trutta* L. 1758, brook trout *Salvelinus fontinalis* Mitchil 1751, Arctic charr *Salvelinus alpinus* L. 1758, and rainbow trout *Oncorhynchus mykiss* Walbaum 1792) and small Cyprinidae used as live bait to fish for trout (European minnows belonging to the *Phoxinus* species complex and vairone *Telestes muticellus* Bonaparte 1837) (Figure 3). Because of such collateral introductions, 19 lakes have both salmonids and cyprinids, and 11 lakes are occupied by cyprinids only (Figure 1), after salmonid populations underwent extinction maybe as a result of interactions with minnows (Borgstrøm, Museth & Brittain, 2010; Tiberti et al., 2022). The remaining 22 lakes only had salmonids (Figure 1).

2.2 | Fish surveys

Only the lakes with confirmed fish presence and with a known composition of fish communities (based on previous surveys and species lists from the protected areas) were included in the present study. All lakes were inspected from one to 37 times (275 surveys) during the study period (2006–2021) using VES. VES consists of walking along the whole perimeter or accessible shoreline of each lake at 2–4 km h^{-1} to monitor the presence or absence of introduced

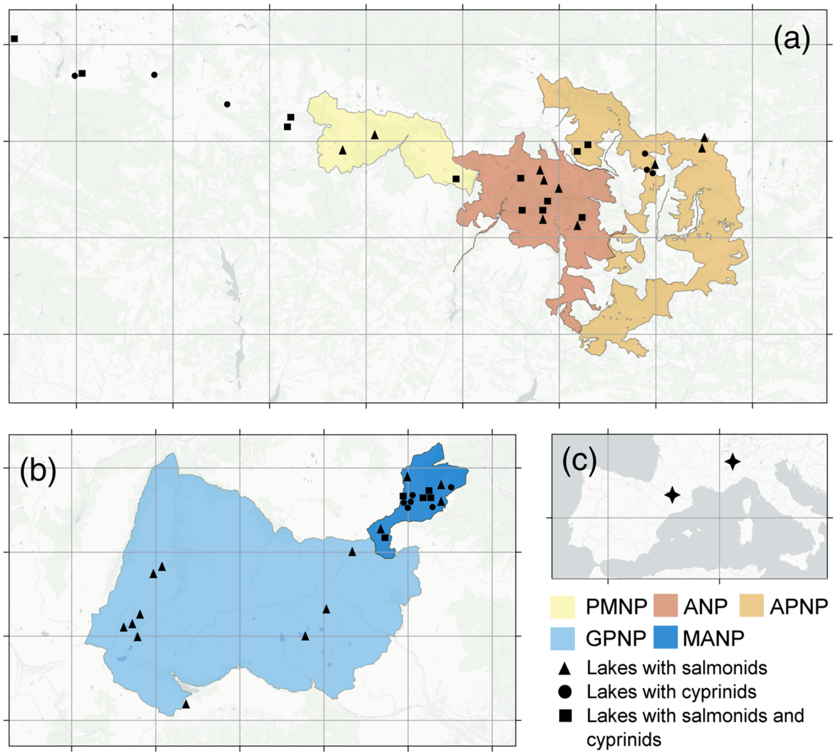

FIGURE 1 Study area and lakes. (a) Aigüestortes i Estany de Sant Maurici National Park (ANP), Alt Pirineu Natural Park (APNP), Posets Maladeta Natural Park (PMNP) (20 km grid). (b) Gran Paradiso National Park (GPNP), and Mont Avic Natural Park (MANP) (10 km grid). (c) Position of the study areas in Europe (1,000 km grid).

FIGURE 2 Typical landscapes around the study lakes. (a) Lake Dres (Gran Paradiso National Park) is situated at 2,048 m above sea level (asl) at the local treeline. (b) Lake Nero (2,671 m asl) is surrounded by sparse alpine vegetation and bare rocks. (c) Lake Naorte (2,200 m asl; Alt Pirineu Natural Park) just below the treeline. (d) The glacial cirque of Dellui (above 2,300 m asl) in Aigüestortes i Estany de Sant Maurici National Park. Fish have been or are being removed from all these lakes within several conservation projects under the LIFE programme.

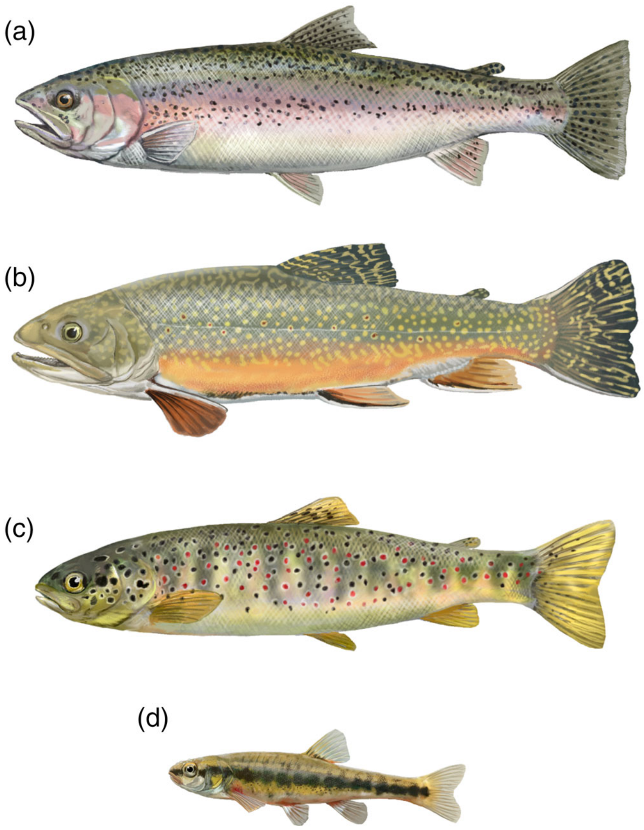

FIGURE 3 Drawings of the most commonly introduced fish species in the Alps and Pyrenees: (a) rainbow trout *Oncorhynchus mykiss*, (b) brook trout *Salvelinus fontinalis*, (c) brown trout *Salmo trutta*, (d) European minnows belonging to the *Phoxinus* species complex. Drawings by Toni Llobet for the project LIFE LIMNOPIRINEUS (LIFE13 NAT/ES/001210).

salmonids and cyprinids by eye. Fish identification at the family level was based on (i) morphological traits — salmonids grow much larger than the cyprinids commonly introduced in mountain lakes (e.g. minnows) and can be distinguished by the presence of the adipose fin, usually observable at relatively long distance; and (ii) behaviour — cyprinids of the same cohorts often aggregate in the littoral zone, whereas salmonids are usually solitary. Considered signs of presence include the observation of salmonids and cyprinids swimming below the lake surface (usually observable in the first 10–20 m away from the shoreline), and the observation of salmonids feeding at the surface, sometimes from considerable distance. In a subset of field surveys ($N = 125$), fish were also counted to calculate two relative density indices, one for salmonids and one for cyprinids. For salmonids, the index was calculated as the number of fish per metre of paced shoreline; for cyprinids, which can move in large groups, exact enumeration was sometimes impossible and they were assigned to five density categories (C0–C4) based on the estimated number of cyprinids per metre of shoreline (fish counts per metre): C0 $=$ 0; 0 < C1 ≤ 0.01; 0.01 < C2 ≤ 0.1; 0.1 < C3 ≤ 1; C4 > 1. The estimated mean duration of VESs varied between 3 and 80 min depending on the perimeter of the study lakes (range: 0.2–2.6 km) and on a typical walking speed of 2–4 km h^{-1}.

In the same lakes, salmonids were sampled with multi-mesh gill nets and cyprinids with fyke nets. In lakes with salmonids, their relative densities were estimated as catch per unit effort (CPUE; number of salmonids per square metre of gill net per day), deploying one to six multi-mesh gill nets, both in the littoral and central part of the lakes, depending on the lake size. To this end, two kinds of gill nets were used: standard nets in the Pyrenean lakes (30 m long $\times$ 1.5 m high, divided into 12 panels with variable mesh size; CEN, 2005) and some different nets in the lakes from the Alps (36 m long $\times$ 1.8 m high, divided into six panels with increasing mesh sizes: 10.0, 12.5, 18.5, 25.0, 33.0, 38.0 mm). In lakes with cyprinids, the CPUE was estimated as the number of cyprinids per fyke net per day deploying two to six fish traps per lake (i.e. fyke nets; 0.5 m wide $\times$ 0.4 m high D-shaped mouth, 4 mm mesh size with a 2 m long central wing or lead) in the littoral area of the lakes (with their mouths facing the shoreline).

2.3 | Statistical analyses

Generalized and linear mixed effect models (GLMMs and LMMs respectively) were used to account for the repeated visual surveys in the same lakes (pseudo replications) and (i) to evaluate whether the detection of salmonids and cyprinids by VES (presence–absence data) depended on fish density and on lake size and (ii) to describe the relationship between the relative densities evaluated by VES and those evaluated by gill-netting and fyke-netting (CPUE).

The performance of VES for fish detection was evaluated using a GLMM fitted by Laplace approximation and an underlying binomial distribution (log link) implemented in the glmer function of the LME4 package (Bates et al., 2007) for the R statistical software, version 4.0.4 (R Development Core Team, 2020), adding salmonid and cyprinid presence–absence evaluated by VES as dependent variables, the CPUEs of salmonids or cyprinids and the lake areas (hectares) as covariates, and lake ID as a random effect; the CPUE of cyprinids evaluated by fyke-netting was log($x + 1$) transformed because it was very right-skewed.

As fish relative density evaluated by VES is a numeric variable for salmonids and an ordinal categorical variable for cyprinids, different statistical models were used to describe the relationship between the VES relative densities and CPUEs for the two fish families. For salmonids, an LMM implemented in the lmer function of the LME4 package, with the densities of salmonids evaluated by VES (fish counts per metre) as the dependent variable, their CPUE evaluated by gill-netting as a covariate, and lake ID as a random effect; for cyprinids, a GLMM for ordinal data was implemented in the mixed_model function of the GLMMadaptive package (Rizopoulos, 2019) with the ordinal density categories (C0–C4) of cyprinids evaluated by VES as the dependent variable, their CPUE (log ($x + 1$) transformed) evaluated by fyke-netting as a covariate, and lake ID as a random effect.

3 | RESULTS

Both introduced salmonids and cyprinids were observed in most VESs (Figure 4a). False absences, which occur when the observers fail to detect species that are present, were relatively infrequent for VESs (11.4% of all VESs for salmonids and 17.9% for cyprinids) and mainly restricted to populations with low CPUEs; detection probability was ~100% for high-density populations (i.e. CPUE ≥ 1 for salmonids and ≥100 for cyprinids; Figure 4a). In a few lakes, false absences were also recorded by gill-netting (in three out of 41 lakes with salmonids, 7.3%) and by fyke-netting (in three out 29 lakes with cyprinids, 10.4%; Figure 4b). In these lakes, repeated VESs made it possible to record the presence of fish. In general, the results suggested that the incidence of false absences for VESs was within reasonable limits, with only slightly worse performance than gill- and fyke-netting.

GLMM results show that the probability of detecting fish by VES significantly increased with fish CPUE measured with gill nets or fyke nets for salmonids and cyprinids respectively (Table 1). The predicted probability of detecting fish by VES quickly stands at values close to 100% as CPUE increases above ~0.5 fish per square metre of net per day for salmonids and ~100 fish per trap per day for cyprinids (Figure 4c). Lake area did not significantly affect the probability of seeing the salmonids but had a marginally significant and positive effect ($P < 0.1$) on the cyprinid detection probability, as a likely consequence of the longer-paced shoreline, which increases the probability of detecting these fish. The effect of lake area is also the reason for the higher variability of predicted values plotted in Figure 4c for the cyprinids compared with salmonids. The relationship between the relative density of salmonids evaluated by VES and by gill-netting was also significant (Table 1). VES data clearly distinguished between lakes with low and high salmonid CPUE, but

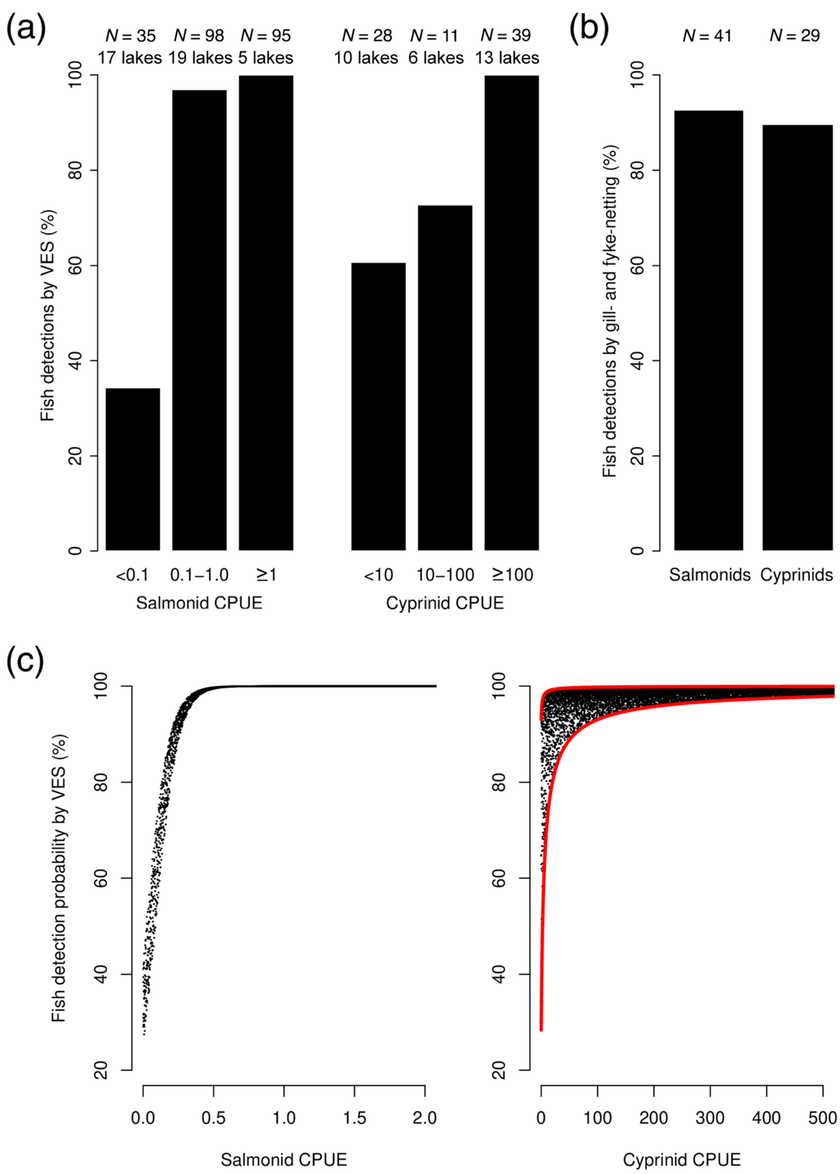

FIGURE 4 (a) Observed proportions of fish detections by visual encounter survey (VES) in lakes with variable densities (catch per unit effort, CPUE) of salmonids (number of fish per square metre per day in 41 lakes) and cyprinids (number of fish per fyke net per day in 29 lakes). The number of surveys *N* and lakes falling into each CPUE interval is reported. (b) Observed proportions of salmonid and cyprinid detections by multi-mesh gill-netting and fyke-netting respectively. (c) Generalized mixed effect model predicted probabilities of detecting salmonids and cyprinids from lakes with variable CPUEs and areas (see Table 1 for a summary of model results). Red lines indicate predicted values for a typically small lake (area 0.1 ha; line standing below predicted values) and a large lake (area 20 ha; line standing above predicted values) including the entire range of variation of the areas of the study lakes. Predictions are based on a simulated dataset of 10,000 CPUE values between 0 and 2 for salmonids and between 0 and 500 for cyprinids (i.e. actual observed ranges) associated with a vector of lake sizes between 0 and 20 ha and randomly associated with each CPUE value.

TABLE 1 Summary of the results of generalized mixed effect models (GLMMs) and linear mixed effect models (LMMs) testing the relationship between (i) the presence/absence of salmonids and cyprinids evaluated by visual encounter survey (VES) with their catch per unit effort (CPUE) and lake area (ha), and (ii) the relative density of salmonids and cyprinids evaluated by VES and their CPUE. A brief model description including the number of observations and grouping factors (i.e. lakes added as random effect) is provided in parentheses

Dependent variable and model description	Fixed effects	β	z	t	P
Salmonid presence/absence by VES					
(Binomial GLMM based on 236 obs. from 41 lakes)	Intercept	−1.10	−2.36	–	**<0.05**
	CPUE	12.52	4.30	–	**<0.001**
	Lake area	0.04	0.71	–	0.48
Cyprinid presence/absence by VES					
(Binomial GLMM based on 79 obs. from 29 lakes)	Intercept	−1.04	−1.38	–	0.17
	log(CPUE + 1)	0.76	2.93	–	**<0.01**
	Lake area	0.18	1.91	–	0.06
Salmonid density by VES (fish m^{-1})					
(LMM based on 85 obs. from 37 lakes)	Intercept	0.01	–	1.65	0.11
	CPUE	0.04	–	3.97	**<0.01**
Cyprinid ordinal density categories (C0–C4) by VES					
(GLMM for ordinal data based on 78 obs. from 29 lakes)	Intercept	−0.28	–	−0.53	0.60
	log(CPUE + 1)	0.64	–	4.71	**<0.001**

Note: Bold type indicates probabilities significant at P < 0.05.

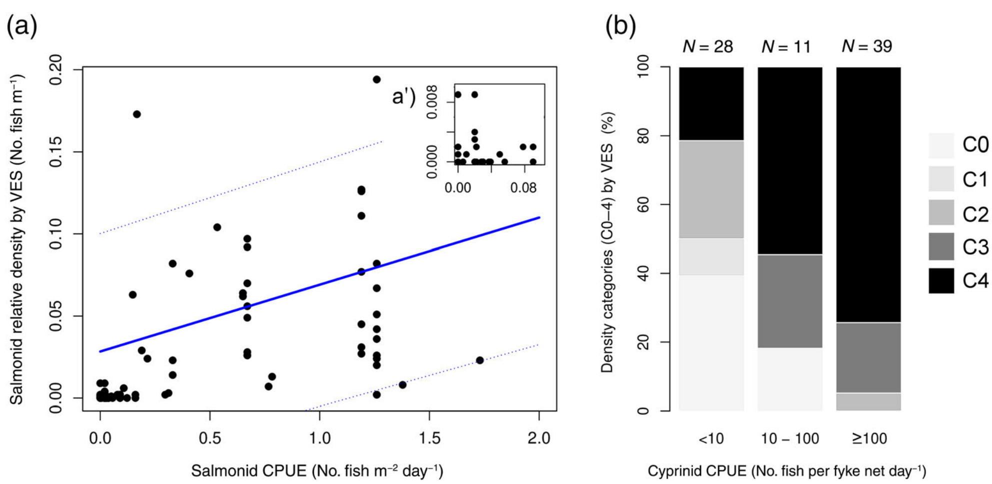

FIGURE 5 (a) Relationship between relative density of salmonids evaluated by visual encounter survey (VES) and by multi-mesh gill nets in 37 high mountain lakes, with insert (a′) showing low-density fish populations with catch per unit effort (CPUE) <0.10; the regression line ±95% confidence intervals from linear mixed effect model (Table 1) are reported. (b) Frequency of the density categories (C0–C4) for cyprinids observed during repeated VESs in 29 high mountain lakes at different CPUE intervals measured by fyke-netting; the number of VESs per CPUE category is reported above the bars.

the variance associated with the relative densities evaluated by VES was often large (Figure 5a), with a relative standard deviation (*RSD* = *SD*/mean) ranging between 0.47 and 1.9 for the lakes with at least five repeated fish counts; the highest RSD values were commonly observed for populations with low salmonid densities evaluated by VES. Cyprinid density categories estimated by VES also significantly reflected the results from fyke-netting (Table 1; Figure 5b). However, as in the case of salmonids, VESs provided highly variable estimates, usually because some lakes with low cyprinid CPUE sometimes fell into the high-density categories if evaluated by VES. For example, some lakes with low cyprinid CPUE were, as expected, usually assigned to the lowest density categories evaluated by VES (C0–C2) but suddenly moved to C4 when large groups of fish aged 0+ appeared.

4 | DISCUSSION

4.1 | The VES as a fish assessment method

This study indicates that VES is an effective method for the detection of both salmonids and cyprinids — the most widespread families of introduced fish in high mountain lakes — in both small and large high mountain lakes. Detection probability is almost 100% for a wide range of population densities, and it stays above 30–50% when densities are low (Figure 4). When compared with gill-netting and fyke-netting surveys, VES provides lower but comparable detection probabilities as well as some gross indications on fish population densities. In addition to its performance, a main advantage of using VES is that it is not time consuming and does not require advanced skills or field and laboratory equipment, such as that commonly used for alternative survey methods (e.g. nets, electrofishing and snorkeling gears, filtering and laboratory equipment for environmental DNA, hydroacoustic devices; CEN, 2005; Achleitner, Gassner & Luger, 2012; Lacoursière-Roussel et al., 2016). The main drawback of VES is that it does not usually allow for species identifications and any kind of fish manipulation (e.g. measuring, tagging, sampling fish). In addition, the high detection power of VES is likely to be attributable to the characteristics of habitats and target species. Clear, high mountain lakes provide good underwater vision along the shoreline, and introduced fish belonging to both families are highly mobile and therefore visible in shallow littoral waters that are used as feeding or nursery areas (Lien, 1981; Tiberti et al., 2017). This is valid for both small and large lakes, and we suggest that VES provides reliable data not only in ponds (where the entire water body can be inspected from the shores), but also in relatively large mountain lakes. There are likely to be some species-specific differences associated with the detection power of VES. For example, observing preferentially littoral species, such as brook trout or minnows (Tiberti et al., 2017), is probably easier than observing Arctic charr, which shows a more pelagic distribution, in particular when co-existing with other salmonids (Klemetsen et al., 2003); in addition, the observation of low-mobility or benthic species can be difficult using VES, but the presence of benthic species in mountain lakes is very uncommon (e.g. *Cottus gobio*; Fam. Cottidae; Pastorino et al., 2019; Tiberti & Splendiani, 2019). However, the fact that false absences by VES were recorded for all the species, but only when they lived at low densities, suggests that the population density, not the species-specific features, is the main factor influencing fish detectability.

Fish density data obtained by VES were highly variable (Figure 5), which we ascribe to the changing environmental conditions during the surveys and to seasonality. VES is only feasible during the ice-free period. Moreover, the presence of waves caused by wind or sun reflection by water can reduce the underwater visibility. In addition, minnows usually reduce their activity in the littoral areas when temperatures fall in the autumn (e.g. late September and October), becoming much less visible, and the abundance of minnows and salmonids can suddenly increase when fish aged 0+ begin to congregate at the lake's shoreline, usually in midsummer. Nevertheless, relative densities evaluated by VES still contain basic (even if gross) information on fish population densities and they can be used to distinguish broadly between low-density and high-density populations. In addition, the observation (or not) of fish aged 0+ during the VESs may provide further information about the reproductive or non-reproductive status of the populations, which is an essential population feature determining its persistence probability under different management scenarios (e.g. with or without periodic stocking).

Other than environmental factors, the quantity and quality of data that can be obtained by a VES depend on the experience of the observer, their personal skills, and the equipment used. There are several precautions that can be taken to improve VES performance: avoiding bad weather and bright sunlight conditions, performing the VES in midsummer to avoid unfavourable seasons, using polarized sunglasses and binoculars to handle sun reflection and distance, and ensuring that some training is given to the practitioners.

VES enables an assessment with good approximation of which lakes have introduced fish together with basic information on their relative density; with minimal training, the same data can be achieved separately for cyprinids and salmonids. Experienced observers can gather additional information, having more chance of identifying fish at the species level. To improve the detection power of VES and the associated quality of data, we suggest performing the surveys in optimal meteorological conditions (i.e. without waves or sun reflections) and when fish are active (in midsummer), and to consider the presence of fish aged 0+.

4.2 | Implications for conservation

There are important conservation issues concerning fish distribution in mountain areas that can be addressed at a relevant biogeographical scale by taking full advantage of the rapidity of VES and considering its limitations. First, knowing which lakes are fishless is fundamental but essential information for the adoption of basic conservation measures aimed at preserving lakes that are still fishless. A list of lakes with and without introduced fish is not available for many mountain regions, but VES could be conveniently used to provide new data and fill this knowledge gap at a large spatial scale. Adopting fishing and stocking bans to prevent new fish introductions to fishless lakes is a neutral measure, which should not incur significant opposition by anglers and stakeholders (Miró & Ventura, 2015), and therefore more likely to be applied at a relevant biogeographical scale. However, a prerequisite for adopting such a measure is having a list of the lakes without fish.

Second, VES could be used for monitoring conservation measures and actions (e.g. fishing and stocking bans, eradication actions; Armstrong & Knapp, 2004; Tiberti et al., 2019) that require updated data and repeated surveys. For example, when fish are eradicated, there is a risk of re-invasion because of incomplete eradication or new introductions; VES can be part of the surveillance and early warning strategy to monitor possible re-invasions. Similarly, VES can be used to monitor the long-term effects of any change in fishery management strategies in mountain areas, both if the changes are implemented for conservation purposes and to further promote recreational angling.

Third, VES can be used to describe the distribution of cyprinids in mountain lakes. VES could help in describing this subtle invasion, which is advancing almost unnoticed over large mountain regions (Miró & Ventura, 2015; De Santis et al., 2021).

In all cases, the huge effort needed to obtain fish distribution data over large mountain regions can be greatly reduced by using VES, enabling several lake surveys per day. To make efforts even more affordable, collaborative monitoring and species distribution models can be used to reduce individual survey effort and the survey area. As VES can be applied by practitioners with minimal training, there is scope to involve stakeholders (e.g. park wardens, anglers) and others in large collaborative or citizen science studies, enabling information to be collected at the desired spatial scale. VES also offers great opportunities for increasing awareness among anglers and the general public of the importance of freshwater conservation and protected areas. Using species distribution models based on already existing but incomplete distribution data may help to identify water bodies where fish cannot thrive (e.g. because the water bodies are too small or above the species' elevational limits), which could be a priori excluded from the monitoring.

In conclusion, we propose VES as a method to help with the elaboration of large inventories, which are necessary to describe in sufficient detail the fish distribution in mountain lakes and to provide basic information for implementing, supporting, and monitoring some urgent conservation measures.

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CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that may have appeared to influence the work reported in this paper.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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